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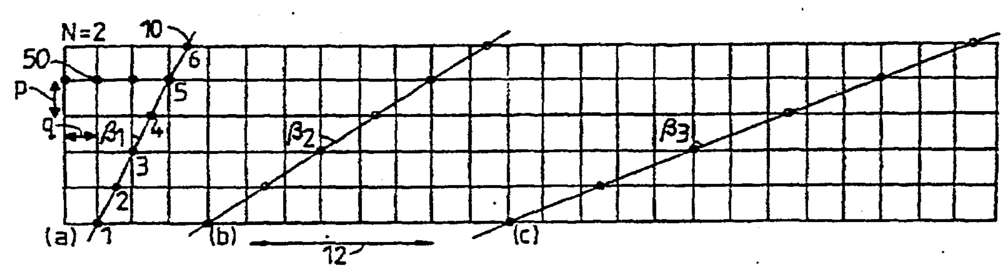

$$\beta = \tan^{-1}\frac{q(iN\pm 1)}{pN} \qquad \text{(I)}$$

(57) Abstract

An ink jet print head with a closest spacing in the vertical matrix direction of p and with a closest spacing in the horizontal matrix direction of q, has parallel ink channels, piezoelectric side walls, nozzles, and a common ink manifold. The channels are arranged in N groups which are successively enabled for droplet ejection and the head is inclined at an angle β to the vertical matrix direction given by formula (I) where i is a positive integer. This provides an increase in the operating frequency and avoids the need for offsetting the nozzles of one group with respect to another.

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DROPLET DEPOSITION APPARATUS

This invention relates to droplet deposition apparatus and in particular to ink jet printers.

For a wide variety of applications including the printing of word processing output, it is desirable for an ink jet printer to be able to deposit the drops at a high density, currently standardised at between 300 and 360 dpi. This corresponds approximately to between twelve and fourteen drops per millimetre (dpmm).

This invention is particularly concerned with ink jet print heads in which ink is ejected through electrical actuation, usually, of a piezoelectric ink chamber wall.

Most prior art ink jet printing technologies of this variety are fundamentally incapable of providing ink channels at this very close spacing. The approach has therefore been adopted with these technologies of angling a print head so as to produce a density of printed dots which is much greater than the density of channels in the print head. Reference is directed, for example, to US-A-4,864,328 which proposes angling a print head at a small angle (7.5°) to the direction of scanning motion of the print head to produce dots at a density of 12dpmm (300 dpi) even though the linear separation between ink nozzles in the print head is greater than 0.5mm. The problem with angling the print head at such a small angle to the scanning direction is that the overall width of the printer is increased beyond the width of the paper by approximately twice, or sometimes three times, the width of the print head, which may amount to 50mm or more. A further problem with inclined print heads is that the closer the angle of the print head to the scanning direction, the greater is the amount of print data requiring to be held in buffer storage.

An alternative approach to this problem is to employ multiple, stacked print heads. This can be expensive.

Recently developed technology, shown for example in EP-B-0 277 703 and EP-B-0 278 590 achieves high densities by utilising transverse displacement of a wall separating two channels to effect droplet

ejection from one of the channels. The wall is usually formed of piezo-electric material deflected in shear mode. With, for example, each channel being separated from its neighbours by only a thin actuating wall, it becomes possible to provide channels at a sufficiently high density to meet desired print quality with the print head orthogonal to the direction of scanning movement; problems of buffer storage and overhang of the print head are thus minimised.

It will be recognised that such a print head has a maximum frequency of operation related to the time taken for a pressure pulse within an ink channel to result in the ejection of an ink droplet. It is an object of one aspect of the present invention to provide, in simple manner, for an increase in the maximum operating frequency.

It has been recognised by the present inventors that whilst the above described technology is capable of achieving a specified linear density of ink channels when depositing a specified drop volume, the maximum operating frequency can be increased by reducing the length of the channels, and making a corresponding increase in the channel thickness. Whilst this necessarily reduces the linear density of channels, the specified print density can be achieved by angling of the print head.

It is convenient to refer to a matrix which represents all possible positions at which drops can be deposited on the substrate. Within this matrix can be defined the direction of scanning movement of the print head relative to the substrate. For convenience, this will be referred to as the horizontal matrix direction. The spacing of matrix points in this horizontal direction is related to the frequency of droplet ejection and the scanning speed. The spacing of matrix points in the orthogonal, vertical matrix direction is determined by the print head configuration. Of course, the labels horizontal and vertical should not be taken as implying any specific orientation in space. Moreover, the matrix in question need not be rectangular. It should further be understood that the term "scanning movement" can mean either single pass or two pass reciprocal motion.

Accordingly, in one aspect, the present invention consists in a method of increasing the operating frequency **F** of a multi–channel droplet deposition head adapted for scanning movement in a scanning direction, comprising parallel channels having a length **L** and a channel thickness d_c; side walls of piezoelectric material having a thickness d_w dividing the channels one from another; a series of nozzles which are uniformly spaced at the spacing **p** of the channels, where **p** equals the sum of channel thickness d_c and wall thickness d_w, and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrical actuating means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, and droplet deposition thereby in lines from said nozzles at a line spacing of **p** orthogonal to the scanning direction; the method comprising increasing the channel thickness from d_c to d_c' with a corresponding increase from **p** to **p'** of the nozzle spacing; reducing the channel length from **L** to **L'**, where **L'/L** is approximately equal to d_c/d_c'; and moving the head from an orientation orthogonal to the scanning direction through an angle approximately equal to $\cos^{-1} p/p'$,towards the scanning direction thereby to permit drops to be deposited in lines at a line spacing orthogonal to the scanning direction comparable to **p**, whilst increasing the operating frequency to **F'** where **F'/F** is approximately equal to **L/L'**.

The invention provides a further, important advantage. It has been recognised by the present inventors that the maximum optical density at which drops can be printed is not ordinarily increased by increasing the number of channels per unit length of the print head. This in fact merely results in the deposition of a larger number of smaller drops, with the print density remaining unchanged for the same operating frequency. However, angling the print head in accordance with the present invention increases the number of channels per unit length in the vertical matrix direction without

reducing the spacing of the channels. There is accordingly a real increase in the print density for the same scanning velocity.

It is a consequence of utilising transverse displacement of a thin wall between two channels to effect droplet ejection from a channel that a very close pressure coupling exists between neighbouring channels. It has been proposed, for example, in EP–B–0 278 590 to deal with this problem by dividing the channels into interleaved groups of channels and permitting actuation of channels from only one group at a time. A further proposal, see EP–A–0 376 532, has been to divide channels into three or more groups. This offers the advantage that any actuated channel will have at least two inactive channels to each side of it. To ensure that drops from adjacent channels are deposited in a straight line upon the print medium, it has been proposed to offset the nozzles of one group of channels with respect to the nozzles of the or each other group of channels. Whilst this approach is usually effective, it may result in complications in the manufacture of the nozzles (typically formed as apertures within a common nozzle plate) and in the management of ink in the nozzle plane. There is, moreover, a limit to the amount by which a nozzle can be offset and remain in register with the corresponding channel. Since the cross sectional area of the nozzle will not always decrease with decreasing channel cross section, this limit may become more acute at higher densities.

It has been recognised by the present inventors that if a print head is disposed at a particular angle, the need for offset nozzles disappears and with it the mentioned complexities.

Accordingly, the present invention consists in a further aspect in a multi-channel droplet deposition head adapted for scanning movement in a horizontal matrix direction relatively to a substrate upon which droplets of liquid are to be deposited along a line in a vertical matrix direction transverse to the scanning direction with a closest spacing in the vertical matrix direction of **p** and with a closest spacing in the horizontal matrix direction of **q**, the head comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the

next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, the channels being arranged in **N** groups which are successively enabled for droplet ejection in respective print phases such that repetitive actuations of any one channel occur no more frequently than once in **N** print phases, wherein the array direction of the head is inclined at an angle to the vertical matrix direction such that on selection of a particular group of channels to eject droplets on respective matrix points, every channel nozzle of each other group is at an interval **jq/N** from a matrix point in the horizontal matrix direction, where **j** is an integer less than **N**.

The present invention consists in still a further aspect in a multi-channel droplet deposition head adapted for scanning movement in a scanning direction relatively to a substrate upon which droplets of liquid are to be deposited along a print line transverse to the scanning direction with a closest spacing in the print line of **p** and with a closest spacing in the scanning direction of **q**, comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, the channels being arranged in **N** groups which are successively enabled for droplet

ejection in respective print phases such that repetitive actuations of any one channel occur no more frequently than once in **N** print phases, wherein the array direction of the head is inclined at an angle β to the print line given by

$$\beta = \tan^{-1}\frac{q(iN\pm 1)}{pN}$$

where i is a positive integer.

There are a number of instances in which it is desirable to construct an ink jet printer having a number of sub–heads, each constructed and aligned in generally the same manner as the unitary heads discussed previously. One such instance is a colour printer where four sub–heads will typically be required, supplied respectively with black, cyan, magenta and yellow ink. Other examples lie in the use of plural sub–heads to increase print density or to produce a stationary print head capable of printing an increased width without scanning.

It has been found by the present inventors that particular advantage can be achieved if plural sub–heads are aligned with a carefully controlled offset.

Accordingly, the present invention consists in still a further aspect in multi–channel droplet deposition apparatus adapted for scanning movement in a horizontal matrix direction relatively to a substrate upon which droplets of liquid are to be deposited along lines in a vertical matrix direction transverse to the scanning direction with a closest spacing in the vertical matrix direction of **p** and with a closest spacing in the horizontal matrix direction of **q**, the apparatus comprising at least two heads each comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and

electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, the channels of each head being arranged in **N** groups respectively, the groups being successively enabled for droplet ejection in respective print phases such that repetitive actuations of any one channel in a head occur no more frequently than once in **N** print phases, wherein the array direction of each head is inclined at an angle to the vertical matrix direction such that on selection of a particular group of channels to eject droplets on respective matrix points, every channel nozzle of each other group is at an interval **jq/N** from a matrix point in the horizontal matrix direction, where **j** is an integer less than **N**, and wherein the two heads are offset a distance **h** in the scanning direction where **h** is an integral multiple of **q**.

The present invention will now be described by way of example with reference to the accompanying drawings in which:–

Figure 1 is a diagrammatic representation of a prior art print head;

Figure 2 is a view similar to Figure 1, showing a prior art modification;

Figure 3 is a diagrammatic representation of a print head according to the present invention;

Figure 4 is a different diagrammatic representation of the print head of Figure 3;

Figure 5 is a diagrammatic representation of different working angles of a print head according to this invention for **N**=2;

Figures 6 and 7 are similar representations for **N**=3 and **N**=4 respectively;

Figure 8 is a block diagram showing certain signal processing aspects of apparatus according to this invention;

Figure 9 is a plan illustrating a signal processing feature;

Figure 10 illustrates, in a diagrammatic form similar to that of Figure 3, an alternative embodiment of the invention in which the printing apparatus comprises two or more sub–heads, with the array directions of the

respective heads collinear; and

Figures 11, 12 and 13 illustrate, in a similar manner to Figure 10, arrangements of two or more sub–heads where the respective array of directions are parallel but offset one from each other.

Referring initially to Figure 1, there is shown a print head 10 in diagrammatic form. The print head is adapted to be scanned in a direction shown at arrow 12 which defines the horizontal matrix direction of a matrix of points at which droplets can be deposited. This matrix is depicted in Figure 1 as a grid. The pitch **q** of the matrix points in the horizontal direction is determined by the frequency of droplet ejection and the scanning speed. The pitch **p** in the vertical matrix direction is determined by the print head arrangement. The matrix is shown as a square grid with **p=q**. This is because dot matrix printers typically utilise a square matrix. It should be understood that other matrix configurations are possible.

Looking more closely at the print head, it will be seen to comprise a parallel array of channels 14, each channel being separated from the adjoining channels by active walls 16 of piezoelectric material. Each channel 14 communicates with a nozzle 18. To eject a droplet from the nozzle 18 of a selected channel, an electric field is applied to one and possibly both active channel walls causing them to displace relatively to the channel. A more detailed description of the print head construction is not necessary for an understanding of the present invention and reference is direction to the above mentioned EP–B–0 277 703 and EP–B–0 278 590.

It will be noted from Figure 1 that with the print head aligned with the vertical matrix direction, the pitch **p** is given by the sum of the channel thickness $\mathbf{d_c}$ and the wall thickness $\mathbf{d_w}$. Thus:–

$$\mathbf{p = d_c + d_w}$$

It is a characteristic of print heads as described that the frequency at which droplets can be ejected is related to the length L of the channel. In simple terms, there is an upper limit placed upon the operating frequency

which is the time taken for an acoustic wave to travel there and back along the length **L** of the channel. The length of the channel **L** is in turn governed by the volume of ink which is to be deposited in a droplet. The smaller the channel thickness $\mathbf{d_c}$ the greater is the length **L** required to produce a droplet of a given volume.

The present inventor has recognised that it is possible to provide the same matrix pitch **p**, with the same drop volume, yet at a higher operating frequency. This is achieved, as shown in Figure 3, by angling the print head away from an orientation parallel to the vertical matrix direction towards the horizontal matrix or scanning direction, whilst increasing the channel thickness from $\mathbf{d_c}$ to a higher value $\mathbf{d_c'}$. This increase in channel thickness permits a decrease in channel length from **L** to a lesser value **L'** where **L'/L** equals $\mathbf{d_c}/\mathbf{d'_c}$. With an angle $\boldsymbol{\beta}$ between the array direction of the print head and the vertical matrix direction, the new nozzle spacing **p'** is given by:-

$$\cos \beta = p/p'$$

There is a further advantage which stems from the angling of a print head as shown in Figure 3. As has been noted above, there is a theoretical limit to the optical density of print that can be achieved with a print head as shown generally in Figure 1. Increasing the number of channels per unit length in the vertical matrix direction would generally result in thinner channels so that whilst more drops are deposited per unit length, each drop is of smaller deposited area. The maximum print density is a critical parameter in dot matrix print technology and a technology which produces an insufficient print density will not be acceptable, even if all other quality standards are exceeded.

By looking at Figure 3, it will be seen that an increase in channel thickness has been achieved without an offsetting decrease in the number of channels per unit length in the vertical direction. There is accordingly an increase in the maximum print density achievable for the same scanning velocity.

With a print head as described, it is advantageous to assign the channel into **N** interlaced groups with printing taking place in cycles, one group of channels per cycle. In the simplest case, channels are allocated to two groups of channels, one group of odd channels and one group of even channels. Since there is a time delay between actuation of the odd channels and actuation of the even channels, steps need to be taken to ensure that, for example, a full vertical line can be printed without "stepping" artifacts appearing as a result of the delayed actuation of the odd channels as compared with the even channels, or vice–versa. It has been noted in the references mentioned above, that one convenient method of dealing with this problem is to offset the nozzles of the odd channels with respect to the even channels. This technique is illustrated in Figure 2. There are, however, close limits on the degree to which a nozzle can be offset with respect to its associated channel. Generally speaking, the smaller the channel the less the nozzle can be offset and remain in proper communication with the channel. There is a risk of performance being effected adversely if a nozzle is significantly offset from the channel axis, particularly if the cross section of the nozzle at the channel side of the nozzle plate (which will usually be greater than the channel cross section at the opposite face of the nozzle plate) encroaches upon the wall thickness.

It may be seen that the technique of offsetting nozzles becomes more complex in the case of an inclined print head, since the direction of the required offset is no longer transverse.

It is recognised in the present invention that the need for offsetting nozzles can be removed entirely by the simple expedient of selecting an appropriate angle for the print head. This is illustrated in Figure 4 where the line 10^1 shows a print head having odd channels **a** and even channels **b**, at the instant at which the **a** channels are enabled for firing. It will be seen that each of the **b** channels lies one half of the matrix pitch **q** from a matrix point. Accordingly, with the print head travelling in the scanning movement to a position 10^2 associated with enabling of the **b** channels, each **b** channel lies at a matrix point. The offset arising from the time of flight of drops has been

ignored in the drawings for simplicity. The angle β which produces this advantageous feature is given by:-

$$\beta = \tan^{-1}\frac{1}{2}$$

There are other angles which provide the same advantage. Thus, Figure 5 shows in highly schematic form three print head orientations a), b) and c), all operating with two groups of channels (**N**=2). By this is meant that the channels are arranged in two interleaved groups with Group I comprising odd channels and Group II comprising even channels. In a first print phase, printing is possible from channels of Group I only, and in a second phase, printing is possible from only channels in Group II. Referring to Figure 5a), the print head has channels and corresponding nozzles evenly spaced along a straight line. In the Figure, the nozzles are numbered **1** to **6**. It will be understood that the channels extend in a direction normal to the plane of the Figure which may also be taken as the plane of the paper on which ink drops are deposited. The print head is scanned in the direction shown by arrow 12 with the velocity of scanning and the frequency of operation being such that the minimum spacing of drops in the scanning direction is **q**. By way of exemplification, there is shown in Figure 5a) at 50 the series of drops deposited from nozzle **5** if this were actuated at the corresponding maximum rate. The spacing **p** of drops along the print line, normal to the scanning direction 12 is determined by the physical spacing of nozzles in the print head and the angle of inclination β_1.

It will be recognised that the channels **1,3,5**... are actuable in alternate phase with channels **2,4,6**... Therefore, with the angle β_1 as shown in the drawings, actuation of an even channel immediately before or after the appropriate neighbouring odd channel will result in the deposition of two drops in a line parallel with the print line. The object has accordingly been achieved of enabling the printing of a full line parallel to the print line utilising a drop from each channel, without the need for physical offsetting of the

nozzles relative to the channels. The angle β_1 can be calculated as $\beta_1 = \tan^{-1} 1/2 = 26.55°$.

It can be seen from Figures 5b) and 5c) that the same result can be achieved with other angles β_2 and β_3. In both cases, the result is achieved that the physical scanning movement between actuation of an odd channel and the appropriate neighbouring even channel is such that drops from the two channels can be deposited along the print line. The derivation of the angle β is set out in Table 1 below.

TABLE I

N	Shift	Head angle	R=P'/P
2	1	$\beta_1 = \tan^{-1} 1/2 = 26.55°$	$\sqrt{5}/2 = 1.118$
2	3	$\beta_2 = \tan^{-1} 3/2 = 56.30°$	$\sqrt{13}/2 = 1.803$
2	5	$\beta_3 = \tan^{-1} 5/2 = 68.20°$	$\sqrt{29}/2 = 2.692$

The Table includes a "shift" value which is the number of horizontal matrix intervals **q** between adjacent channels in only one group. It can only be seen that this shift value takes the algebraic form **iN** ± 1 where **i** is an integer.

Also shown in the Table is the ratio **R** of the physical spacing **P'** of channels or nozzles in the print head relative to the spacing **p** of dots along the print line.

It can now be seen clearly that in each of Figures 5 a), b) and c), the non-firing channels each lie halfway between matrix points in the horizontal direction, that is say (with **N**=2) at an interval **q/N** from a matrix point.

Turning now to Figure 6, this illustrates the case in which nozzles are arranged in three interleaved groups. That is to say, of the nozzles shown in the Figures, numbers 1,4... belong to Group I, numbers **2**,**5**... belong to Group II and number **3**,**6**... belong to Group III. In this case, the smallest angle β_1 which meets the requirements of this invention shown in Figure 6a). It will be seen that if channel **4** is actuated, subsequent actuation in the next

available cycle of channel **3** and then channel **2**, will result in the deposition of a row of dots along the print line. Figure 6b), c) and d) show alternative orientations and the derivation of these angles together with the ratio **R** are set out below in Table II:–

TABLE II

N	Shift	Head angle	R=P'/P
3	1	$\tan^{-1} 1/3 = 18.40°$	$\sqrt{10}/3 = 1.054$
3	2	$\tan^{-1} 2/3 = 33.70°$	$\sqrt{13}/3 = 1.202$
3	4	$\tan^{-1} 4/3 = 53.10°$	$\sqrt{25}/3 = 1.667$
3	5	$\tan^{-1} 5/3 = 59.00°$	$\sqrt{34}/3 = 1.944$
3	7	$\tan^{-1} 7/3 = 66.80°$	$\sqrt{58}/3 = 2.539$

It will be noted that Table II includes the orientation that arises from a shift of 7; this orientation is not shown in Figure 6.

It should be noted that each of the non–firing channels is positioned one third or two thirds of the distance **q** between matrix points, depending upon whether it is to be enabled for firing in the second or the third print phase. More generally, each non–enabled channel is at an interval **iq/N** from a matrix point, with **N=3** in this case.

Turning now to Figure 7, this illustrates a further alternative arrangement in which the channels are arranged in four groups, that is to say **N**=4. The corresponding angles and channel spacing to dot pitch ratios are set out below. No further description of these variants is felt to be necessary.

TABLE III

N	Shift	Head angle	R=P'/P
4	3	$\tan^{-1} 3/4 = 36.90°$	$\sqrt{25}/4 = 1.250$
4	5	$\tan^{-1} 5/4 = 51.30°$	$\sqrt{41}/4 = 1.601$
4	7	$\tan^{-1} 7/4 = 60.25°$	$\sqrt{65}/4 = 2.016$
4	9	$\tan^{-1} 9/4 = 66.00°$	$\sqrt{97}/4 = 2.462$

It will normally be the case that print characters are defined on a grid having equal units in the **x** and **y** directions; that is to say **p** = **q**. This will not always be the case, however. Therefore, the more general case can be quoted in which:-

$$\beta = \tan^{-1}\frac{q(iN\pm1)}{pN}$$

In practice the triple cycle (N=3) has much to recommend it, particularly with shifts 4, 5 and 7. It operates with reduced voltage; the **b** and **c** cycles allow sufficient time for replenishment of channel **a**; and the fact that cross talk is very much reduced enables a constant firing wave form to be employed.

It is instructive to refer at this point to Figure 8 which illustrates in block diagram form the signal processing which serves to derive the firing signals required by a print head according to this invention. Print information is received in a Page Description Language (PDL) by a PDL interpreter 80. A typical PDL is that known commercially as Postscript. The PDL interpreter 80 generates from the PDL input a bit map of the page to be printed, typically in a form which remains printer independent. The bit map is received by a geometric transform unit 82 which transforms the bit map to take into account the angling of the print head and the grouping of channels into successive phases.

The print head will usually scan in opposite directions on successive passes. In the case **N**=2, this will result in odd channels being actuated before even in one pass, and even before odd in the next. Offset correction for the flight time of the drop from the nozzle plate to the paper is also allowed. With **N**=3, the position is more complicated. If the channels are referenced **a,b,c,a,b,c,a...**, the firing order in one pass will be **a,b,c**; in the next pass, in the opposite direction, the firing order will be **a,c,b**.

This is seen in Figure 9 which shows at 90 a print head angled as shown in Figure 6d) having nozzles 94 associated with respective channels

that are arranged in three groups designating **a,b,c...** In the left half of the figure, the print head is moving in the arrowed direction 96 with respect to the paper or other substrate. The channels are enabled for firing in the sequence **a,c,b,a,c,b...** with the channels a being enabled in the position actually shown in the figure. The print data that is required to be supplied to the channels of the print head for the cycle of three print phases is illustrated in the drawing by cross–hatched blocks 98. These show the position in the un–transformed bit map from which information is required to be taken for the specific channels. This function is performed in the geometric transform unit 82. With the channel **a** marked at 100 being taken as the reference, remembering that it is the channels **a** which are enabled for firing in the position shown in the drawing, each successive channel **a** receives information from a point in the bit map displaced five matrix units in the **q** direction and three matrix points in the **p** direction from the preceding channel **a**. It will be noted that each channel **b** is two thirds of an interval from a matrix point (or **2q/N**) and each channel **c** is one third of an interval (or **q/N**). Thus, as noted above, the channels **c** are enabled for firing in the next phase. With respect to the same channel **a** 100, each channel **c** receives information from a matrix point spaced three intervals in the **q** direction and two intervals in the **p** direction. In the final phase, the channels **b** are enabled for firing, receiving information from a point spaced one interval in both the **p** and **q** directions from the channel **a**.

In the right hand part of Figure 9, the position is shown in which the print head is moving in the arrowed direction 102, relative to the paper. In this position it is the channels **b** that are enabled for firing with the channels **c** being one third of an interval from a matrix point and the channels **a** two thirds of an interval from a matrix point. Accordingly, the firing sequence is **b,c,a,b,c,a.** The points in the bit map from which information is required to be taken are illustrated in the same manner.

It will be seen that to allow for the switch in scanning direction, the transform operation is required to reverse the order and either to displace

the starting point or to alter the pixel sequence, these being functionally equivalent.

The transformed bit map is supplied to a wave form generator unit 84 which derives for the selected channels in each group in succession, the wave form necessary to produce the required displacement of the piezoelectric side wall in the print head shown in block form at 86. This wave form may generate a sequence of voltage pulses regions to create specific movements of the wall inwardly and outwardly of the chamber, to accomplish drop ejection and ink replenishment in the channel. The wave form supplied to a specific channel may also carry a correction factor depending in form upon which of the neighbouring channels are being, or are to be fired. The detail of the manner in which firing wave forms are generated forms no part of the present invention.

It has already been stated that there are a number of instances in which it is desirable to construct an ink jet printer having a number of sub–heads, each constructed and aligned in generally the same manner as the unitary heads discussed previously. One such instance is a colour printer where four sub–heads will typically be required, supplied respectively with black, cyan, magenta and yellow ink. Other examples lie in the use of plural sub–heads to increase print density or to produce a stationary print head capable of printing an increased width without scanning.

Figure 10, for example, shows a print head 10 having an array of nozzles in two sub–heads 20a and 20b, each sub–head having a corresponding array of parallel channels having the same dimensions and pitch. The channels in the two sub–heads are drawn for operation in two groups of channels (N=2) with the line of nozzles set at the angle β as shown in Figure 3 and Figure 5a; however, any of the arrangements in Figures 5, 6 or 7 for operation in groups of N=2, 3 or 4 etc. are equally applicable, if the appropriate pitch **p** and angle β are chosen.

When the two sub–heads 20a and 20b are offset along the line intersecting the nozzles in the print head, the arrangement provides a wide print head in which, advantageously, each sub–head 20a and 20b is

supplied by a separate ink manifold. The sub-heads are arranged with the respective array directions collinear and may be formed in a single coextensive ceramic wafer, or may be separate components assembled together in register by an assembly structure (not shown).

The arrangement of Figure 10 is not limited to two sub-heads. One alternative configuration is a print head formed in a single ceramic wafer having four sub-heads for ink of the three primary colours cyan, magenta, yellow and black. Typical examples are angled print heads with four supply manifolds to the following number of actuable channels.

	Cyan	Magenta	Yellow	Black
128 channel head	21	21	21	64
256 channel head	64	64	64	64

For the arrangement of Figure 11 the print head has an array of nozzles in two sub-heads 30a and 30b where the respective array directions are parallel and offset with respect to each other across the direction of motion of the print head (or motion of the print substrate) as illustrated by the arrow. Such a head may, for example, consist of separate components assembled together in register by means of an assembly structure. Such an arrangement serves to provide a print head of increase width and the print head may advantageously be arranged in the form of a stationary print head consisting of a series of component print heads assembled across a page width.

A further configuration is illustrated in Figure 12, in which the print head has an array of nozzles in two sub-heads 40a and 40b offset with respect to each other along the direction of motion as illustrated by the arrow. In one form of the arrangement of Figure 12, the print head comprises four components print heads assembled in register by means of an assembly structure, each component supplied with a different ink colour, i.e. cyan, magenta, yellow and black.

Image quality in each of the arrangements of Figures 10, 11 and 12 above requires that drops are printed in the same dot matrix, the achievement of which places constraints in both design and manufacturing tolerance on the print heads.

Where more than one sub–head is used, the constraints are advantageously that:–

i) One of the groups (there are **N**=2, 3 or 4 groups) is fired synchronously in each sub–head of the print head.

ii) A single, common nozzle plate provides the nozzles for each of the sub–heads so as to ensure the nozzles of all sub–heads are in register.

iii) The dimension $\frac{\underline{\mathbf{h}}}{\mathbf{N}}$ is an integral multiple of **q**.

With **h** as an integral multiple of **q**, drops fired synchronously land on the vertex of the matrix. Figure 10 corresponds to the case **h**=0.

As already stated, nozzle manufacture is straightforward in that they are formed along a straight line at the channel pitch, without nozzle offset corresponding to the phase of operation.

As a complementary step to forming the print head with two or multiple sub–heads, it is also necessary to scan and re–sequence the data order corresponding to the original matrix and to deliver the data via a drive chip in the correct channel and in the correct time sequence. In particular, data for different colours is supplied in different sub–heads and in a modified sequence in time.

As already discussed, the data sequence depends on the pass direction, channels where the data sequence leads in one pass, then lags in the next pass in the opposition direction. Also for the same reason the phase order is reversed from **abc abc** (for **N**=3) in one pass to **acb acb** in the opposite pass direction.

The data sequence is also offset to a degree depending on the line number **i**, being caused to lead or lag by **i/N** matrix vertices or by **i** firing pulses, the offset being advanced or delayed depending on the pass direction.

Where there are two or more sub–heads in a print head offset by ± **h**, there is an additional offset of ±h/**q** matrix vertices in the direction of motion, or **hN/q** firing pulses. Thus a total offset of **i** ± **h N/q** firing pulses is used with the offset being advanced or delayed depending on the pass direction. This is the degree to which data is offset in the geometric transform unit 82 to take into account the angling of the print head, the grouping of channels into **N** phases and the division of the head into two or more sub–heads offset by **h**. The data is also delivered by the drive chip with the specified offset also taking the pass direction into account.

In the case of the head with two or more sub–heads shown in Figure 10 **h** = 0.

A further configuration shown in Figure 13 shows a print head with sub–heads offset by **h**, in which the channels in one sub–head interleave the channels in the second sub–head, so that printing with higher print density may be obtained.

In certain applications, particularly in image reproduction, the "firing" of a channel will not be a binary event and will comprise the application of a defined firing signal to eject a corresponding number of droplets or a droplet of a corresponding size.

CLAIMS

1. A multi-channel droplet deposition head adapted for scanning movement in a horizontal matrix direction relatively to a substrate upon which droplets of liquid are to be deposited along a line in a vertical matrix direction transverse to the scanning direction with a closest spacing in the vertical matrix direction of **p** and with a closest spacing in the horizontal matrix direction of **q**, comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, the channels being arranged in **N** groups which are successively enabled for droplet ejection in respective print phases such that repetitive actuations of any one channel occur no more frequently than once in **N** print phases, wherein the array direction of the head is inclined at an angle β to the vertical matrix direction given by:–

$$\beta = \tan^{-1}\frac{q(iN \pm 1)}{pN}$$

where i is a positive integer

2. A droplet deposition head according to Claim 1, wherein **N**=3 and i=1 or 2.

3. A droplet deposition head according to Claim 1, further comprising signal processing means adapted to receive a bit map of droplets to be

deposited and adapted to derive therefrom parallel actuating signals for said electrically actuable means, said signal processing means including geometric transform means serving to apply a linear transformation to said bit map corresponding to the angle **β**.

4. A droplet deposition head according to Claim 3, wherein respective lines of transformation are provided corresponding to the angle **β** for the respective **N** groups of channels, said lines being mutually displaced in a direction corresponding in the transformation to the horizontal matrix direction by an interval **q/N**.

5. A droplet deposition head according to Claim 3 or Claim 4 and being adapted for scanning in respective opposite senses along the scanning direction, wherein the signal processing means is adapted on reversal of the scanning sense, both to reverse the order of linear transformation and to alter the order of successive enabling of the respective groups of channels.

6. A multi-channel droplet deposition head adapted for scanning movement in a horizontal matrix direction relatively to a substrate upon which droplets of liquid are to be deposited along lines in a vertical matrix direction transverse to the scanning direction with a closest spacing in the vertical matrix direction of **p** and with a closest spacing in the horizontal matrix direction of **q**, the head comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet

ejection therefrom, the channels being arranged in **N** groups which are successively enabled for droplet ejection in respective print phases such that repetitive actuations of any one channel occur no more frequently than once in **N** print phases, wherein the array direction of the head is inclined at an angle to the vertical matrix direction such that on selection of a particular group of channels to eject droplets on respective matrix points, every channel nozzle of each other group is at an interval **jq/N** from a matrix point in the horizontal matrix direction, where **j** is an integer less than **N**.

7. A droplet deposition head according to Claim 6, wherein the closest spacing **p** of deposited droplets in the vertical matrix direction is less than the nozzle spacing by a factor of no more than three.

8. A droplet deposition head according to Claim 6, wherein the angle between the array direction and the vertical matrix direction is greater than 20° and less than 70°.

9. A droplet deposition head according to Claim 6, wherein the angle between the array direction and the vertical matrix direction is greater than 30° and less than 60°.

10. A method of increasing the operating frequency **F** of a multi–channel droplet deposition head adapted for scanning movement in a scanning direction, comprising parallel channels having a length **L** and a channel thickness d_c; side walls of piezoelectric material having a thickness d_w dividing the channels one from another; a series of nozzles which are uniformly spaced at the spacing **p** of the channels, where **p** equals the sum of channel thickness d_c and wall thickness d_w, and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrical actuating means for effecting, on selection of a channel for droplet deposition, transverse displacement of at

least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, and droplet deposition thereby in lines from said nozzles at a line spacing of **p** orthogonal to the scanning direction; the method comprising increasing the channel thickness from $\mathbf{d_c}$ to $\mathbf{d_c'}$ with a corresponding increase from **p** to **p'** of the nozzle spacing; reducing the channel length from **L** to **L'**, where **L'/L** is approximately equal to $\mathbf{d_c/d_c'}$; and moving the head from an orientation orthogonal to the scanning direction through an angle approximately equal to $\mathbf{\cos^{-1} p/p'}$ towards the scanning direction thereby to permit drops to be deposited in lines at a line spacing orthogonal to the scanning direction comparable to **p**, whilst increasing the operating frequency to **F'** where **F'/F** is approximately equal to **L/L'**.

11. Signal processing means for use with a multi–channel droplet deposition head adapted for scanning movement in a horizontal matrix direction relatively to a substrate upon which droplets of liquid are to be deposited along a line in a vertical matrix direction transverse to the scanning direction with a closest spacing in the vertical matrix direction of **p** and with a closest spacing in the horizontal matrix direction of **q**, comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, the channels being arranged in **N** groups which are successively enabled for deposition in respective print phases such that repetitive actuations of any one channel occur no more frequently than once in **N** print phases, wherein the array direction of the head is inclined at an

angle β to the vertical matrix direction given by

$$\beta = \tan^{-1}\frac{q(iN\pm1)}{pN}$$

where i is a positive integer

the signal processing means being adapted to receive a bit map of droplets to be deposited and adapted to derive therefrom parallel actuating signals for said electrically actuable means, and including geometric transform means serving to apply a linear transformation to said bit map corresponding to the angle β.

12. Signal processing means according to Claim 11, wherein respective lines of transformation are provided corresponding to the angle β for the respective **N** groups of channels, said lines being mutually displaced in a direction corresponding in the transformation to the horizontal matrix direction by an interval **q/N**.

13. Signal processing means according to Claim 11 or Claim 12 for use with a droplet deposition head which is adapted for scanning in respective opposite senses along the scanning direction, the signal processing means being adapted on reversal of the scanning sense, both to reverse the order of linear transformation and to alter the order of successive enabling of the respective groups of channels.

14. Signal processing means according to any one of Claims 11 to 13, adapted to receive information in a page description language.

15. Signal processing means according to any one of Claims 11 to 14 in the form of an integrated circuit for mounting as a unit with a droplet deposition head.

16. Signal processing means for use with multi-channel droplet deposition apparatus comprising at least one head adapted for scanning movement in a horizontal matrix direction relatively to a substrate upon which droplets of liquid are to be deposited along a line in a vertical matrix direction transverse to the scanning direction with a closest spacing in the vertical matrix direction of **p** and with a closest spacing in the horizontal matrix direction of **q**, the or each head comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, the channels being arranged in **N** groups which are successively enabled for deposition in respective print phases such that repetitive actuations of any one channel occur no more frequently than once in **N** print phases, wherein the array direction of the head is inclined at an angle to the vertical matrix direction such that on selection of a particular group of channels in each head to eject droplets on respective matrix points, every channel nozzle of each other group in that head is at an interval **jq/N** from a matrix point in the horizontal matrix direction, where j is an integer less than **N**; the signal processing means being adapted to receive a bit map of droplets to be deposited and adapted to derive therefrom parallel actuating signals for said electrically actuable means, and including linear transform means serving to advance or retard data bits by **jq/N**.

17. Signal processing means according to Claim 16, for use with multi-channel droplet deposition apparatus comprising at least two heads mutually offset a distance **h** in the scanning direction where **h** is an integral multiple

of **q**, wherein said linear transform means serves to advance or retard data bits by **jq/N ± h** .

18. Signal processing means according to Claim 17 for use with a droplet deposition head which is adapted for scanning in respective opposite senses along the scanning direction, the signal processing means being adapted on reversal of the scanning sense, both to reverse the order of linear transformation and to alter the order of successive enabling of the respective groups of channels.

19. Signal processing means according to any one of Claims 16 to 18, adapted to receive information in a page description language.

20. Signal processing means according to any one of Claims 16 to 19, in the form of an integrated circuit for mounting as a unit with a droplet deposition head.

21. Multi-channel droplet deposition apparatus adapted for scanning movement in a horizontal matrix direction relatively to a substrate upon which droplets of liquid are to be deposited along lines in a vertical matrix direction transverse to the scanning direction with a closest spacing in the vertical matrix direction of **p** and with a closest spacing in the horizontal matrix direction of **q**, the apparatus comprising at least two heads each comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and

thereby to effect droplet ejection therefrom, the channels of each head being arranged in **N** groups respectively, the groups being successively enabled for droplet ejection in respective print phases such that repetitive actuations of any one channel in a head occur no more frequently than once in **N** print phases, wherein the array direction of each head is inclined at an angle to the vertical matrix direction such that on selection of a particular group of channels to eject droplets on respective matrix points, every channel nozzle of each other group is at an interval **jq/N** from a matrix point in the horizontal matrix direction, where **j** is an integer less than **N**, and wherein the two heads are offset a distance **h** in the scanning direction where **h** is an integral multiple of **q**.

22. A multi–channel droplet deposition apparatus adapted for scanning movement in a horizontal matrix direction relatively to a substrate upon which droplets of liquid are to be deposited along a line in a vertical matrix direction transverse to the scanning direction with a closest spacing in the vertical matrix direction of **p** and with a closest spacing in the horizontal matrix direction of **q**, the apparatus comprising at least two heads each comprising parallel channels having respective side walls which extend in the lengthwise direction of the channels and separate one from the next of the channels in an array direction, a series of nozzles which are spaced at the spacing of the channels and which communicate respectively with the channels for ejection of droplets of liquid from the channels; connection means for connecting the channels with a source of droplet deposition liquid; and electrically actuable means for effecting, on selection of a channel for droplet deposition, transverse displacement of at least one channel separating side wall of that channel to cause pressure change therein and thereby to effect droplet ejection therefrom, the channels of each head being arranged in **N** groups respectively, the groups being successively enabled for droplet ejection in respective print phases such that repetitive actuations of any one channel occur no more frequently than once in **N** print phases, wherein the array direction of the head is inclined at an angle β to the

vertical matrix direction given by:-

$$\beta = \tan^{-1}\frac{q(iN\pm1)}{pN}$$

where i is a positive integer

and wherein the two heads are offset a distance **h** in the scanning direction where **h** is an integral multiple of **q**.

23. Apparatus according to Claim 22, wherein **N**=3 and **i**=1 or 2.

24. Apparatus according to any one of Claims 21 to 23, comprising four heads having respective connection means for connecting the heads with droplet deposition ink of respective different colours.

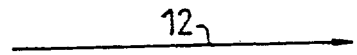


Fig.1.

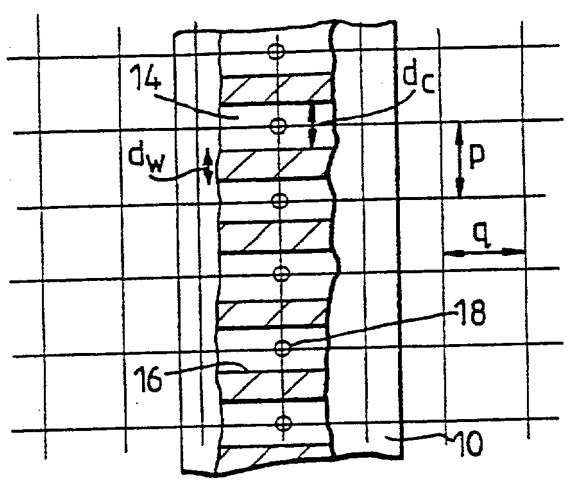
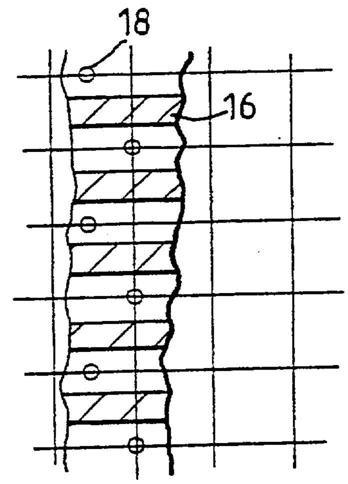


Fig.2.



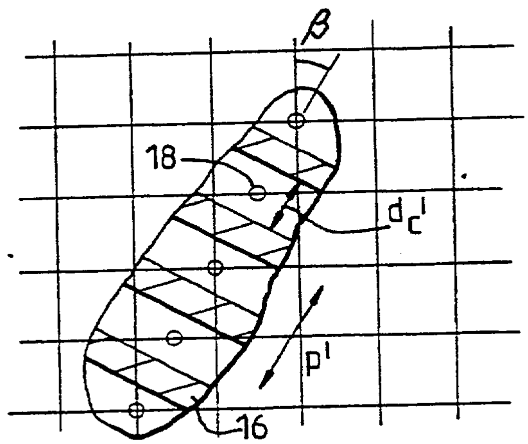


Fig.3.

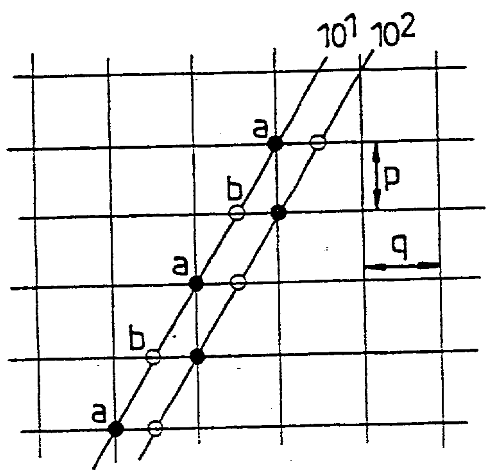


Fig.4.

Fig.5.

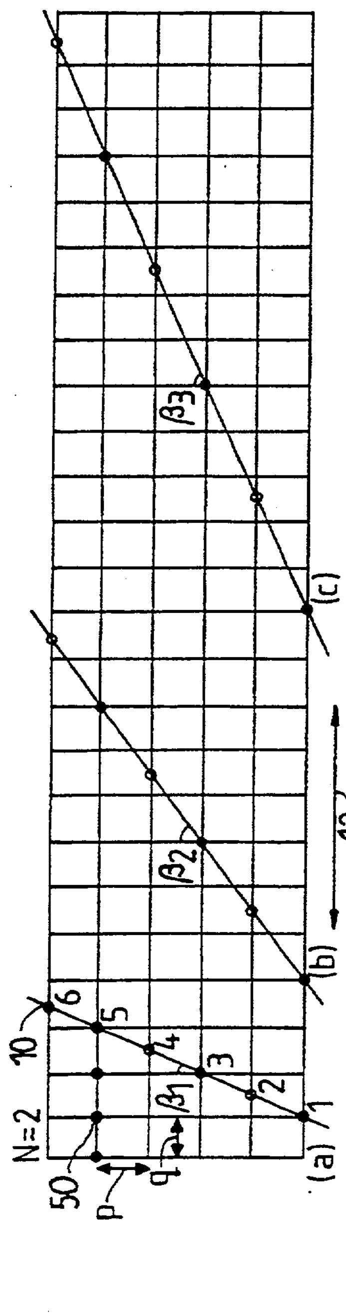


Fig.6.

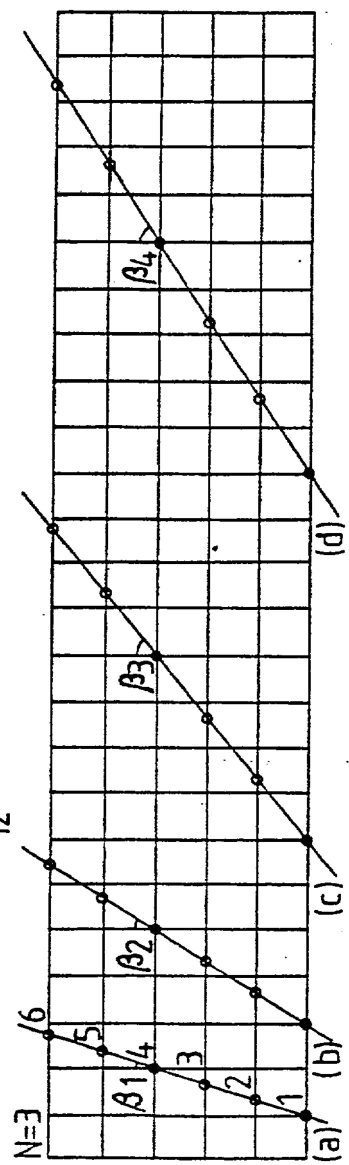


Fig.7.

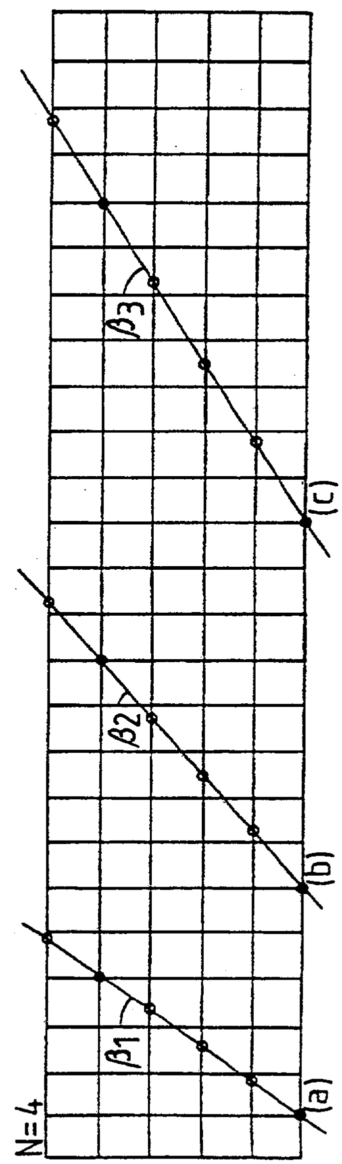


Fig.8.

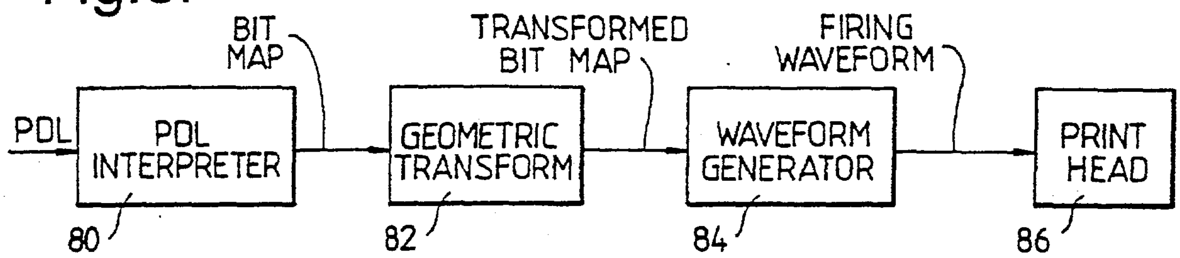


Fig.9.

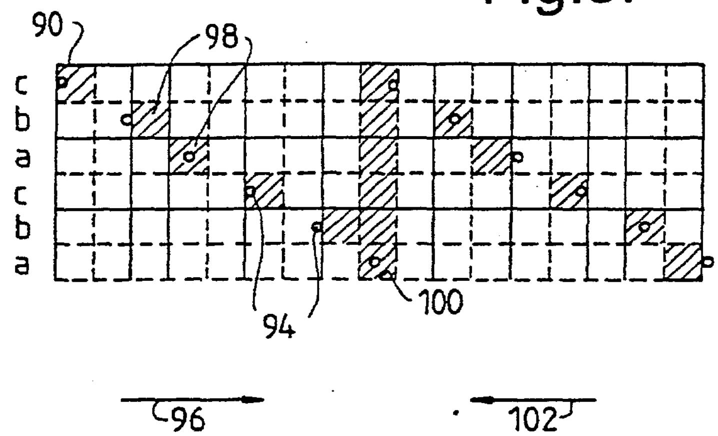
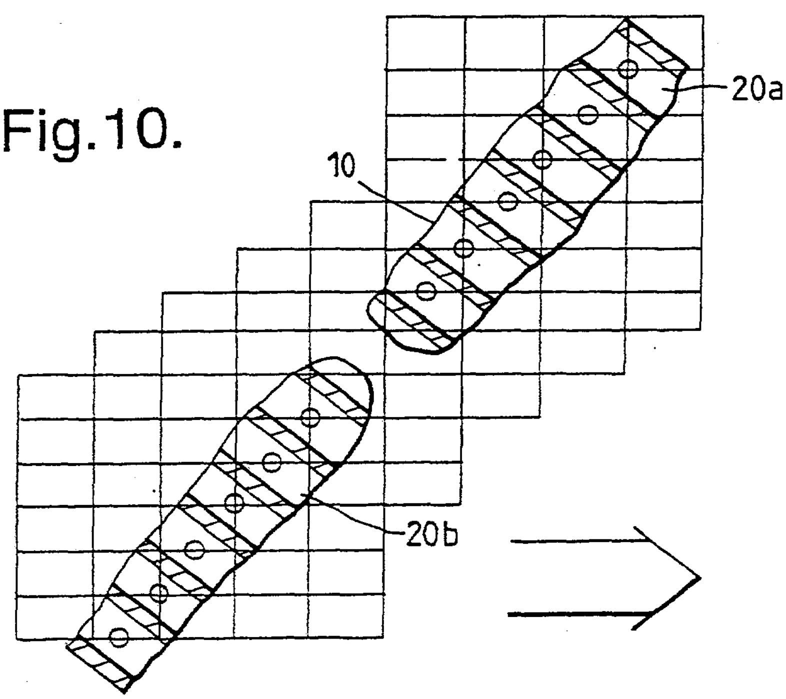


Fig.10.



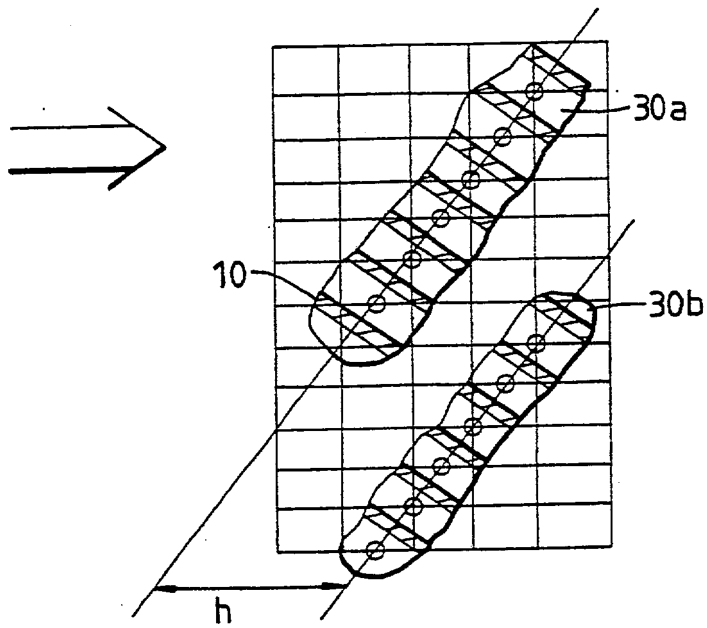


Fig.11.

Fig.12.

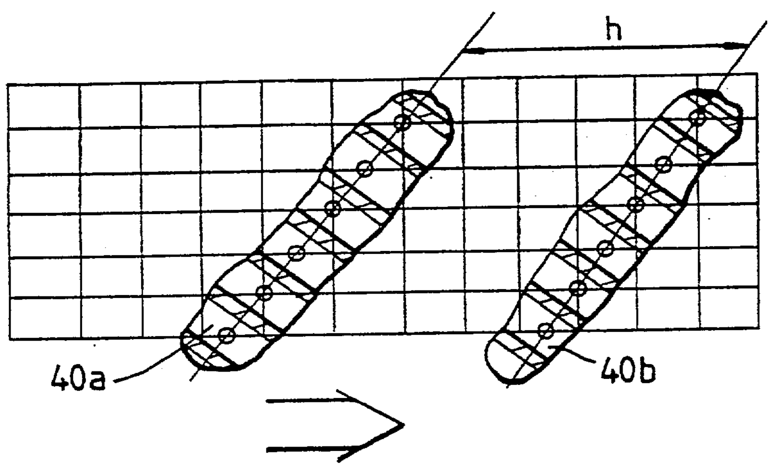
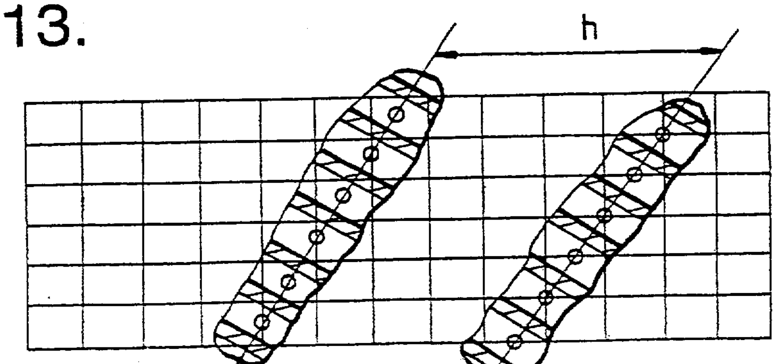


Fig.13.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/01966

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B41J2/51

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B41J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE,A,28 34 658 (LICENTIA PATENT VERWALTUNGS-GMBH) 21 February 1980 see page 5, line 26 - page 6, line 15; figure 3	1,3-24
X	US,A,4 936 210 (UKAI) 26 June 1990 see column 4, line 49 - line 60; claims 1-3; figure 9	1,3-24
X	PATENT ABSTRACTS OF JAPAN vol. 14, no. 247 (M-978) (4190) 25 May 1990 & JP,A,02 067 146 (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) 7 March 1990 see abstract	1,3-24

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
18 November 1994	05. 12. 94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Joosting, T

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/01966

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 273 (M-518) (2329) 17 September 1986 & JP,A,61 095 954 (SHARP CORP) 14 May 1986 see abstract ---	1-24
A	PATENT ABSTRACTS OF JAPAN vol. 8, no. 201 (M-325) (1638) 14 September 1984 & JP,A,59 089 172 (MATSUSHITA DENKI SANGYO KABUSHIKI KAISHA) 23 May 1984 see abstract ---	1-24
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A	US,A,4 739 415 (TOYONO ET AL.) 19 April 1988 see claim 26 ---	10
A	US,A,4 589 786 (FUKUI ET AL.) 20 May 1986 see claim 6 ---	1-24
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 94/01966

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		JP-C-	1716736	14-12-92
		JP-B-	3073467	21-11-91
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		JP-C-	1475617	18-01-89
		JP-A-	56044676	23-04-81
		JP-B-	63024834	23-05-88